DRAINAGE ANALYSIS OF A FEW RIVER BASINS IN BILASPUR REGION, H. P.

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The Region: Bilaspur region constitutes a small part of the western foothill zone of the Himalayas in the State of Himachal Pradesh, India (Fig. 1). It covers an area of about 1167 km² and has been divided into three physiographic regions on the basis of morphometric characteristic of terrain, viz. (i) the Eastern Ranges and Valleys, (ii) the Central Dissected Low Ranges and Valleys. (iii) Naina Devi Kot Range Complex for the selection of ten small drainage basins for the present study. The Eastern Ranges and Valleys have the rock groups of Sub-Himalayas and Lesser Himalayas with the special group of Bilaspur Limestone, while the Siwalik formations have mainly the rocks of Sub-Himalayas. Structurally, the area is very complicated due to repeated folding, faulting and thrusting. The thrust-faults have brought out the older formations over the younger formations. On the whole, the region is constituted by various rock types which range in age from Pre-Cambrian to Pleistocene.

The altitude in general varies from about 321 m ASL in the south western part and Sutlej valley to 1,967 m ASL along the Bahadurpur Dhar in the Southeastern part of the study region. The climate of the entire tract is subtropical, except in high altitudinal zone of mountaneous terrain where it is temperate. In general, the region with moderately high relative relief (100-200 m), a moderate dissection index (0.1-0.3), moderately steep slope (10°-20°) and a moderate drainage frequency (5-10 streams/km²) has a moderate drainage density (3-4 km/km²). Here, the quantitative analysis includes stream orders, stream numbers, stream lengths, bifurcation ratios, stream length ratios, relief ratios, elongation ratios, basin circularity, basin sinuosity, drainage density, stream frequency and geomorphic stage of development of the area on the basis of hypsometric integrals.
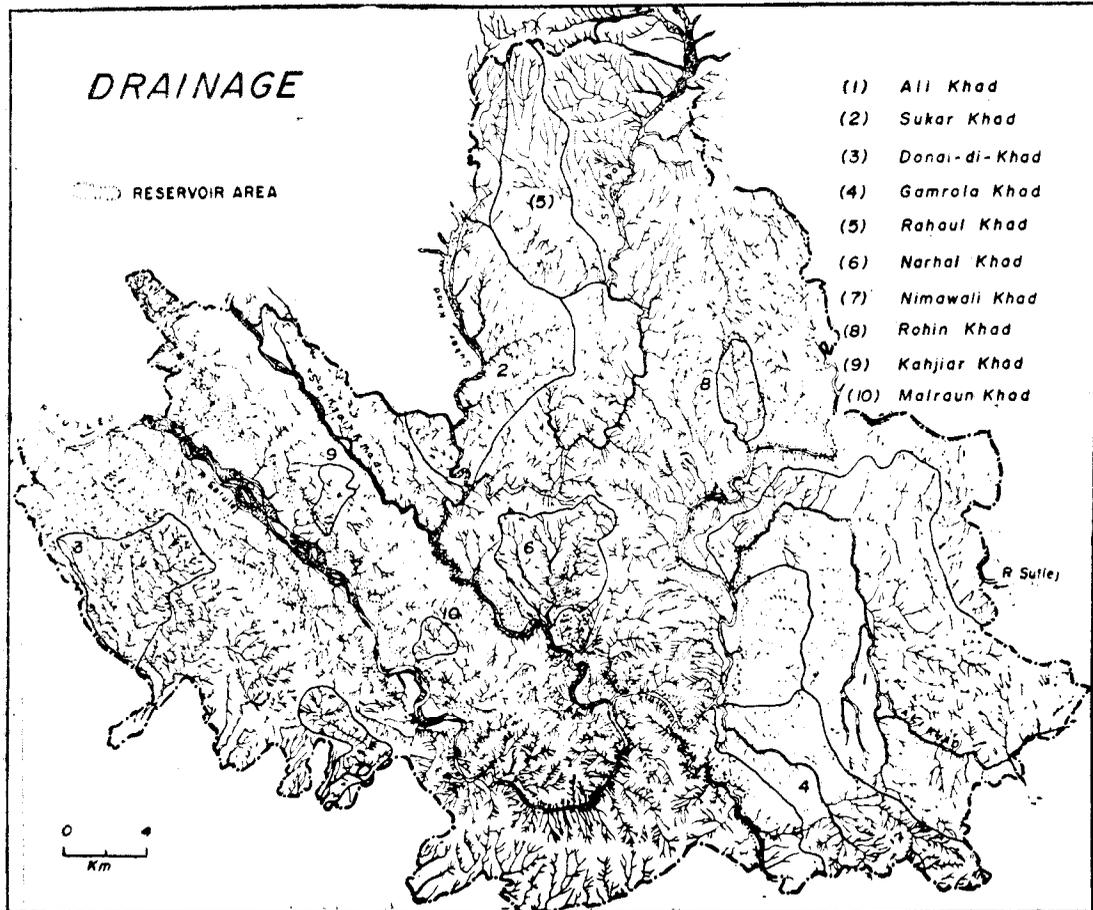
Materials and Methods

The study is primarily based on published and derived data. For the analysis of the drainage characteristics and relief, intensive use has been made of topographical sheets (1:63360 and 1:50,000) published by the Survey of India. All the basin area has been measured by planimeter and length of segments by rotameter The Sutlej, as the main river, forms antecedent drainage system in the area under investingation (Fig. 2). Out of its many big and small tributaries Gambhar, Gamrola, Alikhad and Sirkhad also form the antecedent drainage system, as these four tributaries flow cutting the main ranges, locally known as 'dhar'. Out of four major tributary basins, two basins of Alikhad and Gamrola have been selected along with other eight selected tributary basins.
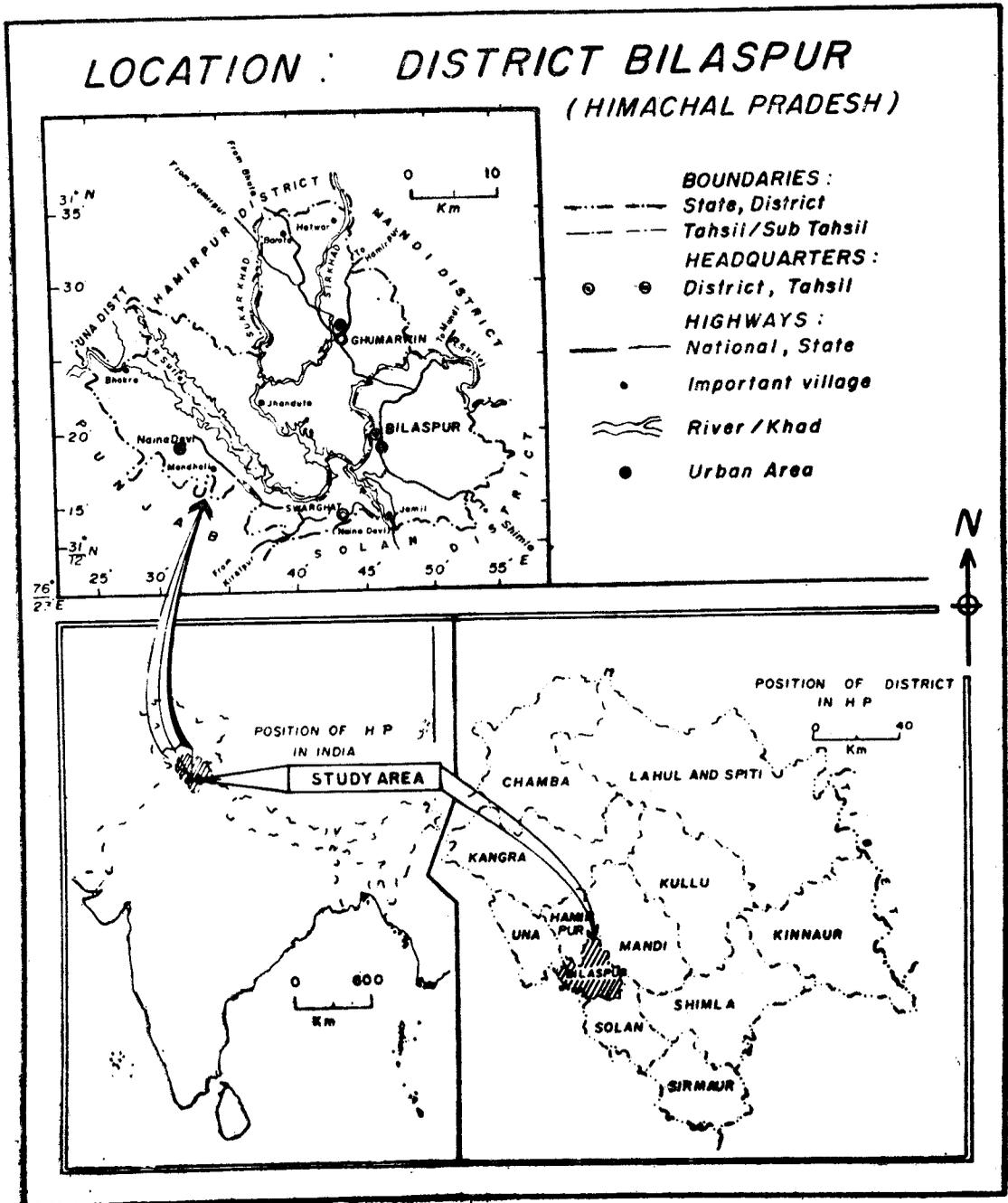
These tributary basins have been selected from the three major physiographic regions (the Eastern Ranges and Valleys, the Central Dissected Low Ranges and Valleys, and the Naina Devi Kot Range Complex). The great Sutlej basin has not been selected as a sample drainage basin because its origin and mouth both are beyond the limits of the study region. The important tributary basins which are

DRAINAGE

RESERVOIR AREA

(1) Ali Khad
(2) Sukar Khad
(3) Donai-di-Khad
(4) Gamrola Khad
(5) Rahaul Khad
(6) Narhal Khad
(7) Nimawali Khad
(8) Rohin Khad
(9) Kahjiar Khad
(10) Malraun Khad

selected as sample drainage bas'ns are Ali Khad, Gamrola Khad (the origin regions of both Khads are out of the study area, but the whole valley has been selected for a systematic drainage basin analys's), Rohin Khad, Rahaul Khad, (its orig'n is also out of study area) Narhal Khad, Malraun Khad, Kajh'ar Khad, Nimawali Khad and Donaidi-Khad. The mouth reg'ons of last two basins are beyond the limits of the study region (Fig. 2). The small tr'butaries of the Sutlej, spec'ally in Naina Devi and Kot range devi and Kot range divis'on, are more or less affected by the construct'on of the artific'al reservo'r. Finally, f eld checks are carried about to verify certain facts.

Stream Order

The first step in the quantitative analys's of dra'nage basin is the designa-tion of the stream orders. According to Strahler (1964), the f'rst order streams are those wh'ch have no tributaries. The second order streams are those wh'ch have as tributories only first order chan-nels. Where two second order channels jo n, a segment of th'rd order is formed. When two third order segments join a fourth order channel :s formed and so on. The trunk stream through wh'ch all discharge of water and sediments pass in the stream segment is of highest order (Strahler, 1964).

STREAM ORDERING
Strahler Method
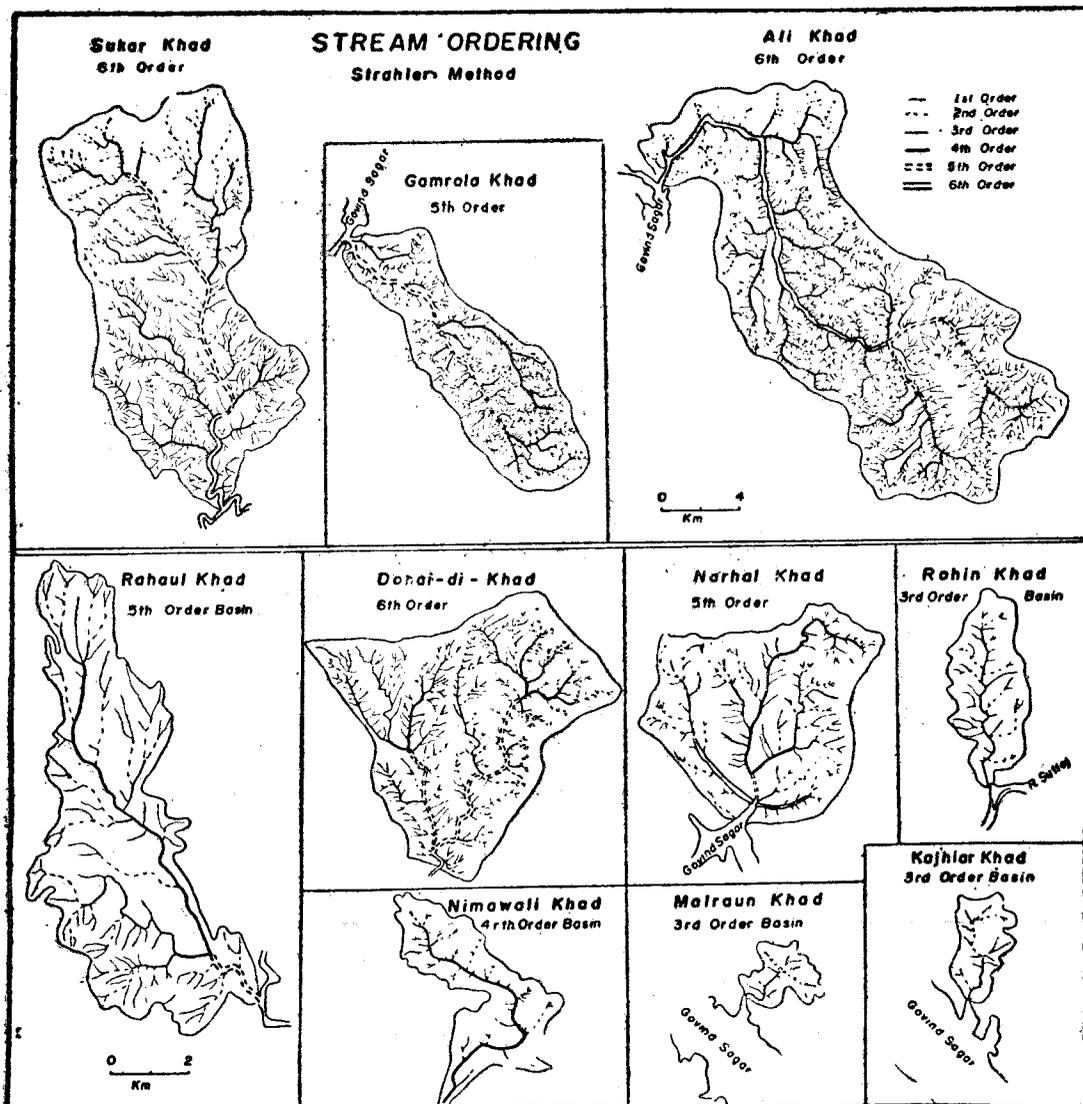
In the present study, the streams of the Bilaspur basin have been ranked according to the Strahler's stream ordering system (Fig. 3 and Table 1). The Sutlej river is the trunk stream of the study area. Its important tributaries, which have been selected as sample drainage basins are of sixth, fifth, fourth and third orders. The size of the individual tributary basins has been calculated by planimeter. The following table gives the stream order and size of 10 tributary basins besides those of the trunk basin, i.e. Sutlej.

The perimeters of all third, fourth, fifth and sixth order basins have been drawn on the map following their watersheds. It is noteworthy in the above table that the area of the largest tributary basin, namely the Ali Khad, which is of sixth order, is 232.57 km², while that of the smallest tributary basin namely the Mulraun Khad, which is of third order,

Table 1. Stream orders and size of ten sample basins

Basin No.	Name of basins	Order	Area (km²)
1.	Ali Khad	Sixth	232.57
2.	Sukar Khad	Sixth	188.12
3.	Donai-di-Khad	Sixth	27.59
4.	Gamrola Khad	Fifth	70.34
5.	Rahaul Khad	Fifth	31.23
6.	Narhal Khad	Fifth	20.53
7.	Nimawali Khad	Fourth	8.88
8.	Rohin Khad	Third	6.96
9.	Kahjiar Khad	Third	3.45
10.	Malraun Khad	Third	2.76

is 2.76 km² only. The variation in order and size of the tributary basins is largely due to physiographic and structural conditions of the region. For example Malraun Khad, confined to a small area of 2.76 km² is located in the lower altitudinal zone (500 m-911 m) along the central watershed of Sutlaj which is characterised by steep slopes of the Siwalik beds. In contrast, the Ali Khad valley with an area of 232.57 km² has developed over cherty Limestones of Krol, Claystones of Upper Dharmsala and Bilaspur Limestone in the higher altitudinal zone (500 m–1883 m). The elongated and less-elongated shape of Gamrola Khad, Nimawali and Rahaul Khad, the streams which join the Sutlej and Sir Khad in south of the region respectively, have been formed as a result of the thrust-zone while the valley of Ali Khad is guided by Main Boundary Fault.

Stream Numbers

The total of order-wise stream segments is known as stream number.

Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with an order number. According to the Strahler's scheme of stream ordering system, the sample basins of Bilaspur region have been ordered. Table 2 shows the order-wise stream numbers of the tributary basins of study region. The maximum frequency in the case of first order streams is unambiguous in all cases. The data of stream numbers and cumulative mean length both have been plotted on logarithmic graph against stream orders. The graph (Fig. 4) shows the number of streams decreasing as the order of streams increases.

Stream Lengths

The total stream lengths of all sample basins of various orders have been computed with the help of Rotameter from topographical sheets. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in the basins of increasing order (Strahler, 1964).

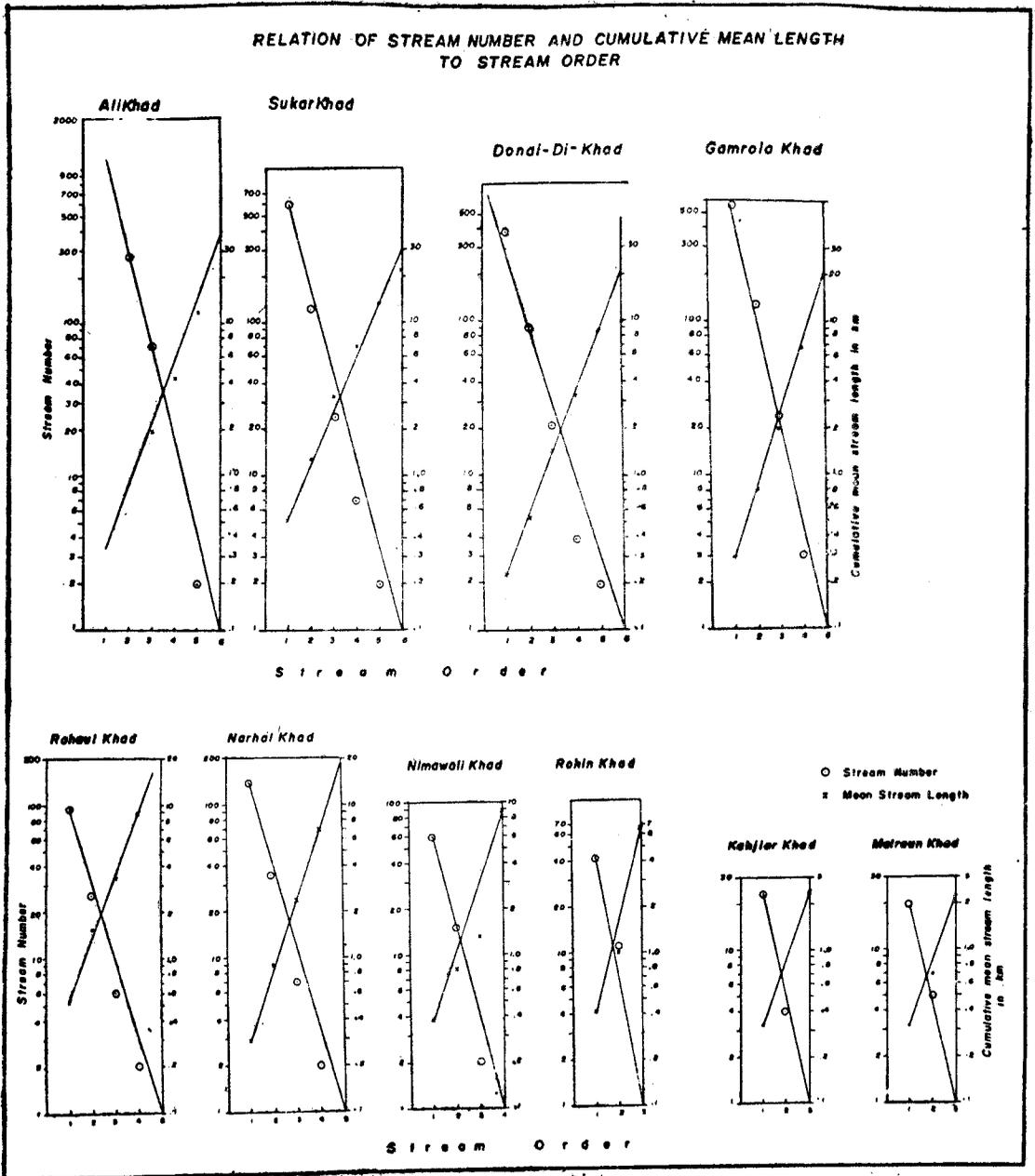RELATION OF STREAM NUMBER AND CUMULATIVE MEAN LENGTH
TO STREAM ORDER

Table three depicts that the total length of stream segments is maximum in case of first order streams. In almost all cases, the basin length decreases as the order increases and it is lowest in case of the highest order streams. Exceptions, however, are marked in case of the basins of Ali Khad, Gamrola Khad and N mawali Khad, where these stream segments do not make the basins of Ali Khad, Gamrola Khad and Nimawali Khad, where these stream segments do not make geometric series. In Ali Khad basin the

Table 2. Order-wise stream numbers of sample drainage basins

Basin No.	Name of basin	Order-wise stream numbers					
		I	II	III	IV	V	VI
1.	Ali Khad	1162	274	70	16	2	1
2.	Sukar Khad	595	122	24	7	2	1
3.	Donoi-di-Khad	389	90	21	5	2	1
4.	Gamrola Khad	547	127	24	3	1	—
5.	Rahaul Khad	84	26	6	2	1	—
6.	Narhal Khad	139	35	7	2	1	—
7.	Nimawali Khad	59	15	2	1	—	—
8.	Rohin Khad	42	11	1	—	—	—
9.	Kahjiar Khad	23	4	1	—	—	—
10.	Malraun Khad	19	5	1	—	—	—

total length of fifth order stream segments (15.10 kms) is less than that of the sixth order stream segments (26.44 kms). This inconsistancy is due to relief variation and rock conditions over which these stream channels occur. It is noted that the fifth order streams of this basin, mostly occurring in the high altitudinal zone (845 m – 1274 m),are characterized by steep slopes while sixth order streams occur comparatively in lower altitudinal zone (500 m – 841 m) with a moderate slope. Same conditions are also marked in the Gamrola and Nimawali Khad basins, where the total length of stream segments is 13.85 kms in fourth order and 1.00 km in third order, while those of the fifth and fourth oder are 15.74 kms and 7.50 kms respectively. These variations are also due to variation in rocks and relief.

Table 3. Order-wise stream length (km) of sample drainage basins

Basin No.	Name of basin	Order-wise stream lengths (in kms)					
		I	II	III	IV	V	VI
1.	Ali Khad	398.4	151.80	75.58	37.79	15.10	26.44
2.	Sukar Khad	304.0	96.05	48.75	26.25	12.25	7.00
3.	Donai-di-Khad	88.16	27.90	18.89	9.12	10.83	1.26
4.	Gamrola Khad	160.30	64.88	30.86	13.85	15.74	—
5.	Rahaul Khad	49.00	26.50	10.75	11.00	2.25	—
6.	Narhal Khad	40.94	20.78	10.38	9.12	2.00	—
7.	Nimawali Khad	22.50	6.50	1.00	7.50	—	—
8.	Rohin Khad	17.50	6.50	5.75	—	—	—
9.	Kahjiar Khad	7.50	3.75	1.15	—	—	—
10.	Malraun Khad	6.1	1.9	1.55	—	—	—

Mean Stream Lengths

Mean stream length is a dimensional property revealing the characteristic size of the components of a drainage network and its contributing basin surfaces (Strahler, 1964). It is measured by rotameter from topographical maps and then calculated with the help of the formula, $Lu = \dfrac{L}{Nu}$

Where Lu is the mean stream length, L is the total stream length and Nu is the number of segments (N) of stream order (u). The cumulative mean stream lengths, on a long scale, have been plotted against stream orders on an arithmetic scale (Fig. 4). The plot pro-

duces more or less a straight line regression of positive exponential form' (Strahler, 1971, p. 487). There are, however, a few exceptions, as in case of Donai-di-Khad, Rahaul Khad and Narhal Khad (Table 4.). The mean length of Donai-di-Khad in fifth order is greater than the sixth order, and the fourth order mean stream lengths of Rahaul Khad and Narhal Khad are relatively greater than that of the fifth order streams. This type of disturbed relation of mean stream length with the order may be explained by more sinuous courses of the fifth (Ali Khad) and fourth order (Narhal and Rahaul Khad) stream segments due to the lithologic variations.

Table 4. Order-wise mean stream length of ten sample basins

Basin No.	Name of basins	Order-wise mean stream lengths (km)					
		I	II	III	IV	V	VI
1.	Ali Khad	0.34	.0.55	1.07	2.36	7.55	26.55
2.	Sukar Khad	0.51	0.78	2.03.	3.75	6.12	7.00
3.	Donai-di-Khad	0.22	0.31	0.89	1.82	5.41	1.26
4.	Gamrola Khad	0.29	0.51	1.28	4.61	15.74	—
5.	Rahaul Khad	0.52	1.01	1.79	5.50	2.25	—
6.	Narhal Krad	0.29	0.59	1.48	4.56	2.00	—
7.	Nimawali Khad	0.38	0.43	0.50	7.50	—	.—
8.	Rohin Khad	0.42	0.59	5.75	—	—	—
9.	Kahjiar Khad	0.32	0.93	1.15.	—	—	—
10.	Malraun Khad	0.32	0.38	0.38	—	—	—

Bifurcation Ratio

The ratio between successive order is defined as 'Bifurcation Ratio'. Its irregular tendency is seen from one order to the next order. The irregularities

of the bifurcation ratio is dependent upon the lithological and geological development of the drainage basins (Strahler, 1971, p. 484). According to Strahler 'The ratio of number of seg-

mentts of a given order (Nu) to the number of segments of the higher order (Nu+1) is termed the bifurcation ratio, Rb (Strahler, 1964). Where 'Rb' is the bifurcation ratio, 'Nu' is the number of segments of a given order, and Nu+1 is the number of segments of the next higher order, and

$$Rb = \frac{Nu}{Nu + 1} \quad . \text{ Bigurcation ratio defines}$$

the analysis of tributary junction angles.

Table 5 shows the bifurcation ratio between streams of various order of sample drainage basin of Bilaspur region. In general the bifurcation ratio varies from 2 to 6 in the area under study but higher values are marked in a few basins as Ali Khad (8.00 between IV to V order), Nimawali Khad (7.50 between II to III order) and Rohin

Khad (11.00 between II to III order). High bifurcation ratio of 5.75 is noted between first and second order streams of Kahjiar Khad, 5.08 is seen between II and III order streams in case of Sukar Khad, 5.29 (II and III order) in case of Gamrola Khad, 5.00 for both Narhal and Malraun Khad. The high bifurcation ratios are the result of large variation in stream frequency between successive orders. For example, Rohin Khad basin is 3rd order basin, the number of stream frequency of IInd and IIIrd is II and 1 only. It gives high bifurcation ratio i.e. II.

It is concluded that higher values of bifurcation ratio indicate a mature topography which is the result of the process of drainage integration. This postulation is the result of geologic and tectonic characteristics in the area under investigation.

Table 5. Bifurcation ratios of the selected drainage basins

Basin No. (1)	Name of basin (2)	Order-wise ratio				
		I–II (3)	II–III (4)	III–IV (5)	IV–V (6)	V–VI (7)
1.	Ali Khad	4.24	3.91	4.37	8.	2
2.	Sukar Khad	4.87	5.08	3.42	3.5	2
3.	Donai-di-Khad	4.32	4.28	4.20	2.5	2
4.	Gamrola Khad	4.30	5.29	8.00	3.00	—
5.	Rahaul Khad	3.61	4.33	3.00	2.00	—
6.	Narhal Khad	3.97	5.00	3.50	2.00	—
7.	Nimawali Khad	3.93	7.50	2.00	—	—
8.	Rohin Khad	3.81	11.00	—	—	—
9.	Kahjiar Khad	5.75	4.00	—	—	—
10.	Malraun Khad	3.80	5.00	—	—	—

Stream Length Ratio

Horton (1945, p. 291) states that the length ratio (RL) is the ratio of the mean length (Lu) of the segments of order (u) to mean length of segments of the next lower order (lu–1), wh'ch tends to be constant throughout the successive orders of a water-shed. The length ratios of the dra'nage bas'ns of the study region have been calculated by applying the following formula:

$$RL = \frac{\overline{Lu}}{\overline{Lu-1}}$$

Where RL is the stream length ratio, 'Lu' is the mean stream length of order 'u' and 'Lu—1' is the mean length of the segments of next lower order.

Table Six gives the stream length ratios of ten sample drainage bas'ns of the study area. It is observed that the length ratio between first and second order streams varies from 1.02 in case of Nimawali Khad, but in case of Kahjiar Khad it is 2.81. The Nimawali Khad and Kahjiar Khad bas'ns have an altitude of 376 m to 1005 m and 500 m to 809 m with moderate to steep slope regions respectively. The length rat.o between second and third order streams varies irregularly from 1.23 (Kahj'ar Khad) to 4.07 (Malraun Khad — a small basin), but it is 9.74 in the Roh'n Khad basin. These aforesaid bas'ns are located in the altitudinal zones of 500-809 m, 500 m - 900 m, and 522 m - 1201 m respect.vely. Similarly variations are noted in the stream length rat'os of the th'rd and fourth order, from 1.84 to 3.57 (Sukar Khad — 519 m - 1086 m and Gamrola Khad 500 m - 1955 m) but higher value is noted in case of N'mawali Khad (376 - 1005 m), i.e. 15.00, between IIIrd and IVth order. S'm'larly, the stream length ratio fluctuates from 0.41 (Rahaul Khad, 643-996 m) to 3.41 (Gamrola Khad, 500 m - 1955 m) between the fourth and fifth order streams, and 0.23 to 5.50 for Donai-d'-Khad (345-911) and Ali Khad (500 m to 1883 m) between the fifth to sixth order streams.

Table 6. Stream length ratios of ten selected basins of Bilaspur region

Basin No.	Name of basin	Order-wise stream length ratio				
		I–II	II–III	III–IV	IV–V	V–VI
1.	Ali Khad	1.61	1.93	2.20	8.19	3.50
2.	Sukar Khad	1.54	2.56	1.84	1.63	1.14
3.	Danai-di-Khad	1.37	2.90	2.02	2.97	0.23
4.	Gamrola Khad	1.71	2.53	3.57	3.41	—
5.	Rahaul Khad	1.94	1.77	7.07	0.41	—
6.	Narhal Khad	2.02	2.49	3.08	0.44	—
7.	Nimawali Khad	1.13	1.16	15.00	—	—
8.	Rohin Khad	1.40	9.74	—	—	—
9.	Kahjiar Khad	2.81	1.23	—	—	—
10.	Malraun Khad	1.18	4.07	—	—	—

Relief Ratio

Relief ratio (Rh) is the ratio of maximum basin relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956, p. 112). Relief ratio is calculated by using the following formula:

$$Rh = \frac{H}{Lb}$$

where Rh is the relief ratio, H is the total relief and Lb is the basin length. Table 7 shows the relief ratios of sample selected drainage basins. The relief ratio values vary from 0.021 to 0.186. The minimum value is observed in Sukar Khad (0.021), and maximum (0.186. in Malraun Khad basin. The high relief ratios of Rohin Khad, Kahjiar Khad and Malraun Khad are 0.130, 0.108, 0.186 respectively, which show that these basins are composed of resistant rocks. Similarly, the relief ratios of other tributary basins vary between 0.021 and 0.083, suggesting a terrain of that less resistant rock. In contrast, Ali Khad and Gamrola Khad valleys are compossed of both resistant as well as less resistant rocks.

Table 7. Relief ratio of tributary basin

Basin No.	Name of Basin	Total relief (m)	Maximum length (km)	Relief ratio
1.	Ali Khad	1383	34.40	0.040
2.	Sukar Khad	567	27.00	0.021
3.	Donai-di-Khad	566	8.00	0.070
4.	Gamrola Khad	1455	20.00	0.072
5.	Rahul Khad	354	12.65	0.027
6.	Narhal Khad	322	6.72	0.047
7.	Nimawali Khad	629	7.50	0.083
8.	Rohin Khad	679	5.20	0.130
9.	Kahjiar Khad	309	2.85	0.108
10.	Malraun Khad	411	2.20	0.186

Elongation Ratio

According to Schumm (1956, p. 612), 'elongation ratio (Re) is defined as the ratio of the diametre of a circle of the same area as the basin to the maximum basin length'. Strahler states that this ratio runs between 0.6 and 1.0 over a wide variety of climatic and geologic types. Values near 1.0 are found in typical regions of low relief while values from 0.6 to 0.8 are generally associated with strong relief and steep ground slopes (Strahler, 1964, pp. 4-51). The ratio is obtained by using the following formula:

$$Re = \frac{2\sqrt{A/\pi}}{L}$$

where Re is the elongation ratio, 2 is constant, A = area, $\pi = 22/7$ and L is the maximum basin length. Table eight gives the elongation ratio of ten tributary basins of the area under study. Out of these ten basins, Donai-di-Khad (0.81) basins are oval. Ali Khad (0.61), Sukar

Khad (0.65), Gamrola Khad (0.50), Rahaul Khad (0.50), Nimawali Khad (0.60) basins are elongated; the remaining two basins, Kahjiar Khad and Narhal Khad are less elongated. None of the basins is wholly circular, or extremely elongated. The varieties of the elongated shape of the tributary basins are due to the guiding effect of thrusting and faulting.

Table 8. Elongation aad circularity ratios of selected drainage basins

Basin No.	Name of the basin	Elongation ratio		Circularity ratio	
		Maximum basin length (km)	Elongatioa ratio	Basin perimeter (km)	Circularity ratio
1.	Ali Khad	28.00	0.61	82.40	0.43
2.	Sukar Khad	23.50	0.65	70.00	8.48
3.	Donai-di-Khad	7.31	0.81	24.32	0.58
4.	Gamrola Khad	18.88	0.50	44.40	0.44
5.	Rahaul Khad	12.55	0.50	36.10	0.30
6.	Narhal Khad	6.51	0.78	19.53	0.67
7.	Nimawali Khad	5.60	0.60	19.00	0.31
8.	Rohin Khad	5.20	0.57	12.50	0.56
9.	Kahjiar Khad	2.85	0.73	7.50	0.77
10.	Malraun Khad	2.20	0.85	7.00	0.70

Basin Circularity

For the outline form of drainage basins (Strahler, 1964, pp. 4-51) and Miller, 1953, p. 8), a dimensionless circularity ratio has been used as a quantitative measure. where (Rc) is defined as the ratio of basin area (Au) to the area of a circle (Ac) having the same perimeter as the basin. It is affected by the litho-

thological character of the basin. It is basin.

$$Rc = \frac{\text{Area of basin}}{\text{Area of circle}} = \frac{4\pi A}{p^2}$$

with the same perimeter, where Rc is basin circularity, P is basin perimeter, 4 is constant value and A is the area of basin.

Table eight gives the circularity ratio of the selected basins of Bilaspur region. It is a significant ratio, which indicates the stage of dissection in the study region. Its low, medium and high values are indicative of the youth, mature and old stages of the cycle of the tributary basins of the study region. The circularity ratio in the area varies from 0.30 for Rahaul Khad to 0.77 for Kahjiar Khad. The high values of circularity index for Kahjiar Khad indicate the late mature stage of topography while Kahjiar Khad basin aitually represents youth stage of topography. This anomaly is due to diversity of slope, relief and structural conditions prevailing in this drainage basin. The water divide of this basin is also affected by a major anticline i.e. Changar Talai anticline which controls its mature broadly. Rahaul Khad basin (0.30 Ri) presents the youth stage of topography because of its natural development. Similarly, Nimawali Khad basin is in its mature stage (according to visual perctption) but its circularity index (0.31) reveals an early mature stage of topography. Malraun Khad basin is also in an early mature stage, but its circularity index (0.70) indicate salate nature stage. Ali Khad (0.43), Sukar Khad (0.48), Donoi-di-Khad (0.58), Gamrola Khad (0.044), Narhal Khad (0.67) and Rohin Krad basins (0.56) cllearly indicated the mature of topography.

Sinuosity Index

Sinuosity deals with the pattern of the channel of a drainage basin. In general, its value varies from 1 to 4 or more. It is a quantitative index for interpreting the significance of streams in the evolution of landscapes and beneficial to Geomorphologists, Hydrologists and Geologists. Webster defines sinuous as bending, winding, curving and deviat-

ing. Its significance for the geomorphologists is related to the stage of landforms. Streams equal to the valley, streams slightly smaller than the valleys and the streams small compared to valleys express youth, maturity and old stage of topography respectively (Mueller, 1968, p. 372). For the measurement sinuosity index, Mueller (1968, p. 374-375) has developed some important computations which deal with various types of sinuosity indices. He also defines two main types i.e. topographic and hydraulic sinuosity index concerned with the flow of natural stream courses and with the development of flood plains rspectively. Here calculations of various types of sinuosity indices are made on the basis of the following formula (Mueller, 1968, p. 375):

Channel Index (CI) CL/Air (Hydraulic and Topographic Sinuosity),

Valley Index (VI) VL/Air (Topographic Sinuosity), Hydraulic

Sinuosity Index (HSI) = % equivalent of CI-VI/CI-1, Topographic

Sinuosity Index (TSI) = % equivalent of VI-I/CI-I, Channel Sinuosity Index (CSI) = CL/VL and Standard Sinuosity Index (SSI) = CI/VI

Table 9 gives the channel Index (CI), Valley index (VI), hydraulic sinuosity index (HSI), Topographic sinuosity (TSI), Channel Sinuosity index (CSI) and Standard Sinuosity Index (SSI) of the ten selected drainage basins of the area under investigation. Mueller (1968, p. 373) states that topographic sinuosity is outstanding during youth when hydraulic sinuosity is negligible, conversely, hydraulic sinuosity is outstanding during the old stage after most of the topopraphic sinuosity has been removed.

Table 9

Channel, hydraulic, topographic sinuousity indices of the selected tributary basins of Bilaspur region (H.P.)

Basin No.	Name of basin	CL (km)	VL (km)	Air (km)	CI	VI	CSI	HSI	TSI	SSI
1.	Ali Khad	37.96	36.80	25.60	1.48	1.43	1.03	0.11	0.89	1.03
2.	Sukar Khad	29.30	28.52	22.50	1.30	1.26	1.02	0.14	0.86	1.03
3.	Donai-di-Khad	8.80	8.20	6.72	1.30	1.22	1.07	0.26	0.74	1.06
4.	Gamrola Khad	21.28	20.42	18.72	1.13	1.09	1.04	0.31	0.69	1.03
5.	Rahaul Khad	13.85	13.05	12.35	1.12	1.05	1.06	0.58	0.42	1.06
6.	Narhal Khad	8.80	8.00	5.92	1.48	1.35	1.10	0.27	0.73	1.09
7.	Nimawali Khad	8.04	8.00	5.40	1.55	1.48	1.05	0.13	0.87	1.04
8.	Rohin Khad	5.40	5.20	5.00	1.08	1.08	1.03	0.50	0.50	1.03
9.	Kahjiar Khad	3.25	3.00	2.75	1.18	1.09	1.08	0.50	0.50	1.08
10.	Malraun Khad	2.75	2.60	2.00	1.37	1.30	1.05	0.19	0.81	1.05

The channel sinuosity indices of the selected tributary basins showing on table 9 range from 1.02 to 1.10 (for Sukar Khad and Narhal Khad). This low value of channel sinuosity indicates the less in sinuous nature of these streams. The topographic sinuosity indices are high and hydraulic sinuosity indices are low in all selected tributary basins of the study region except two basins i.e. Rohin Khad and Kahjiar Khad. These two basins have 40% of each topographic and hydraulic sinuosity which indicates the early mature nature of topography in the area under investigation. The increasing ratio of topographic sinuosity indices (Table 9) of aforesaid basins indicates youthful topographic nature but these basins are seen in early mature stages of their development (Hypsometric Integral (Strahler, 1962, pp. 1158-1170). This anomaly in the fluctuation of stream sinuosity is due to time and stage of basin development in a geological context. Normally in this maturity stage, the river should have meandering shapes but this departure (SSI-Indices) from the normal is because of the structural controls exerted by the lithology and the different parallel bordering ranges here and there.

Drainage Density and Stream Frequency

According to Horton (1932, p. 347) drainage density defines the length of streams per unit of the drainage area. Here, in the context of selected drainage basin analysis, it is derived by using the formula i.e. $D = Lu/Au$, where 'D' is the drainage density, 'ΣLu' is the total length cumulated for each stream order within a given basin area 'Au'. Like density, Horton (1932, p. 357) defined stream frequency as the total number of channels within a basin area. It is also computed by the formula i.e. $F = \Sigma Nu/Au$, where F is the stream frequency 'ΣNu' is the total number of stream segments of all orders within the given basin area 'Au'.

Table 10 gives the drainage density of selected tributary basins. The drainage density varies from 2.62 to 5.66 km/km^2 for the Sukar Khad and Donai-di-Khad respectively. The stream frequency of the area varies from 3.99 to 18.41 for the same aforesaid basins. The development of stream segments in this valley is more or less affected by rainfall and temperature.

Hypsometric Curve

The form of hypsometric curve and the value of the integral are important element in the analysis of landscape and show marked variations differing with the stage of development and geologic structure. In the stage of youth hypsometric integral is large, but it decreases as the landscape is denuded towards a stage of maturity and old age (Strahler, 1952).

The percentage hypsometric curve (Area-Altitude) is a ratio of relative height and relative area with respect to the total hight and the total area of a drainage basin. It has been calculated with the help of following ratio:
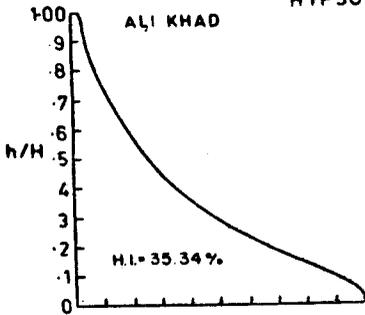
(i) a/A, where 'a' is the area enclosed by a pair of contours and 'A' is the total basin area which is represented on the Abscissa and (ii) h/H, where 'h' is the highest elevation between each pair of contours above the base and 'H' is the total basin height. It is plotted on the ordinate (Fig. 5).

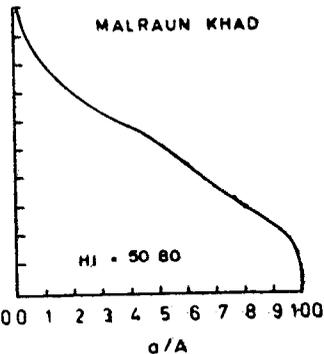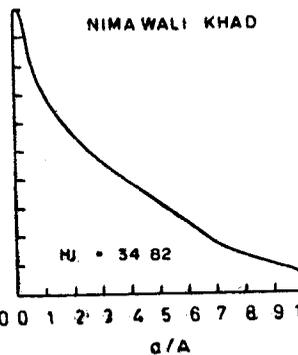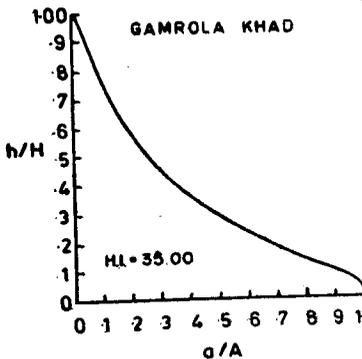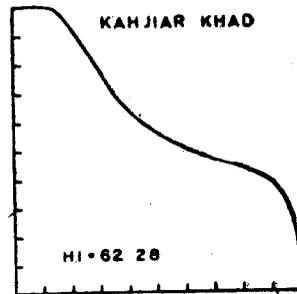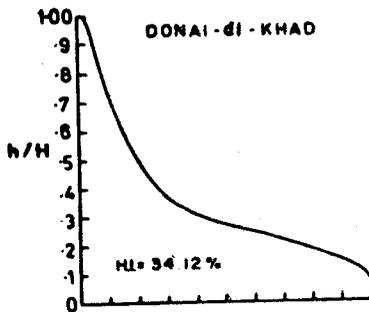Table 10 reveals, inter alia, the hypsometric integrals according to Strahler's method (1952) for the selected
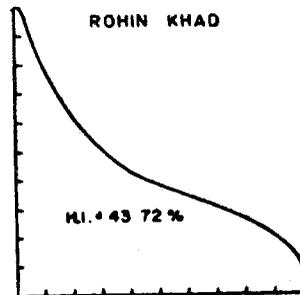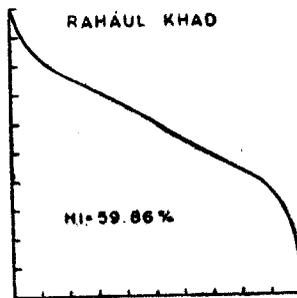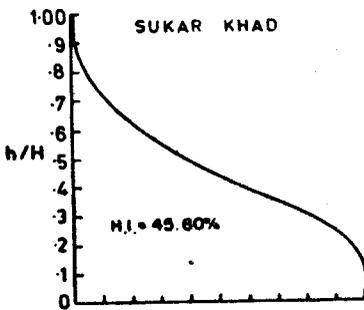
Table 10.

Drainage density, stream frequency area and hypsometric sub-surface integral

Basin No.	Name of basin	Total basin area (km²)	Drainage density (km/km²)	Drainage frequency	Hypsometric integral %	Remarks for Hypsometric Integral
1.	Ali Khad	232.57	3.03	6.55	35.34	Late maturity
2.	Sukar Khad	188.12	2.62	3.99	45.80	Mature stage
3.	Donai-di-Khad	27.59	5.66	18.41	34.12	Late maturity
4.	Gamrola Khad	70.34	4.06	9.98	35.00	Late maturity
5.	Rahaul Khad	31.23	3.19	4.13	59.86	Youth stage
6.	Narhal Khad	20.53	4.05	8.96	49.40	Middle Maturity
7.	Nimawali Khad	8.88	4.22	8.67	34.82	Late maturity
8.	Rohin Khad	6.96	4.27	7.75	43.72	Middle Maturity
9.	Kahjiar Khad	3.45	3.59	8.11	62.28	Youthful Stage
10.	Malraun Khad	2.76	3.46	9.05	50.80	Early Maturity

HYPSOMETRIC CURVES FOR SELECTED DRAINAGE BASINS

ALI KHAD

INDEX
h/H = RELATIVE HEIGHT
a/A = RELATIVE AREA
H.I. = HYPSOMETRIC INTEGRAL

H.I.= 35.34 %

SUKAR KHAD — H.I.= 45.60%

RAHAUL KHAD — H.I.= 59.86 %

ROHIN KHAD — H.I.= 43.72 %

DONAI-di-KHAD — H.I.= 34.12 %

NARHAL KHAD — H.I.= 49.40

KAHJIAR KHAD — H.I.= 62.28

GAMROLA KHAD — H.I.= 35.00

NIMAWALI KHAD — H.I.= 34.82

MALRAUN KHAD — H.I.= 50.80
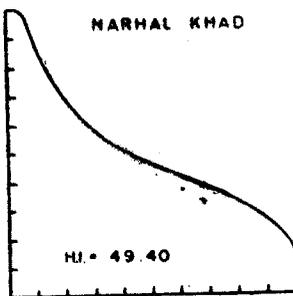
drainage basins. Here hypsometric integrals have been calculated for each selected drainage basin separately. The values of the hypsometric integrals and the form of the hypsometric curves, taken together, help to identify the stage of basin development. It is noted that the hypsometric integrals, in the study area, range from 34.12% for the Donai-di-Khad basin to 62.28% for that of Kahjiar Khad. These values of hypsometric integrals show (Table 10i the youth. early maturity to middle maturity, late maturity and mature stage of their development. According to the spread of the river basins and the size of the valleys, it may be easily inferred that the area is in a sub-mature stage.

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